IDS

(19) Europäisches Patentamt
European Patent Office
Office europ´en des brevets

(11) Publication number: 0 635 735 A1

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 94304213.5

(22) Date of filing: 10.06.94

(51) Int. Cl.[6]: G02B 6/12

(30) Priority: 21.07.93 US 95278

(43) Date of publication of application:
25.01.95 Bulletin 95/04

(84) Designated Contracting States:
DE FR GB IT

(71) Applicant: LITTON SYSTEMS, INC.
5500 Canoga Avenue
Woodland Hills, CA 91367 (US)

(72) Inventor: Chang, Chin Lung
1823 West Lighthall Street
West Covina,
California 91790 (US)
Inventor: Choi, Youngmin Albert
5410 Isabella Court
Agoura Hills,
California 91302 (US)
Inventor: Douglas, Sheri Lee
3901 Elkwood Street
Newbury Park,
California 91320 (US)

(74) Representative: Marlow, Nicholas Simon
Reddie & Grose
16, Theobalds Road
London WC1X 8PL (GB)

(54) Electro-optic waveguides and phase modulators and methods for making them.

(57) Lithium niobate waveguides for light and lithium niobate channel waveguide electro-optic phase modulators for light include sufficient lithium ions such that, when an electrical signal of known value is applied to such waveguides and modulators, the phase of light passing through the waveguide or the modulator changes to a desired value within a time period that is substantially instantaneous.

EP 0 635 735 A1

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to lithium niobate optical waveguides and to channel waveguide electro-optic phase modulators.

Background of the Invention

Before now, the amplitude of light waves passing through lithium niobate optical waveguides, such as the waveguides used in fibre-optic gyros (FOG's), has failed to change substantially instantaneously to a desired value upon application of an electrical signal to the waveguide. Instead, the amplitudes of such light waves has tended to change gradually, requiring time periods of a few hundred microseconds or more to attain and maintain the desired value. This gradual change of amplitude is sometimes called phase relaxation, and seriously degrades the performance of FOG's containing them.

A need exists for methods for making optical waveguides and for making channel waveguide electro-optic phase modulators that exhibit substantially no phase relaxation and that can therefore improve the performance of FOG's containing them by at least one order of magnitude.

SUMMARY OF THE INVENTION

This invention relates to lithium niobate optical waveguides, and to lithium niobate channel waveguide electro-optic phase modulators which contain sufficient lithium ions such that the phase of a light signal passing through the waveguide or modulator changes substantially instantaneously to a desired value when a known electrical signal, such as a step function electrical signal, is applied to the modulator or waveguide. More particularly, the quantity of lithium ions in the waveguide or modulator is preferably sufficient to cause the phase of a light signal passing through the waveguide or phase modulator to change to a desired, steady-state value in not more than about one microsecond.

Waveguides or modulators according to the invention include sufficient lithium ions such that, when an electrical signal is applied to such a waveguide or modulator, the amplitude of light passing through the waveguide or modulator changes to a desired value substantially within the transient time of the applied electrical signal. This invention also relates to methods of making such optical waveguides and such channel waveguide electro-optic phase modulators.

One method for making these waveguides and phase modulators comprises subjecting a lithium niobate waveguide, before the waveguide undergoes proton exchange and thermal annealing, to heat treatment in the presence of oxygen. This heat treatment preferably takes place at a temperature in the range of about 400 °C to about 1000 °C, at about atmospheric pressure, in the presence of sufficient oxygen and of sufficient lithium niobate powder or other lithium ion source, and for a time period sufficient to diffuse the needed quantity of lithium ions into the optical waveguide or phase modulator. The proton exchange and thermal annealing steps of this method are disclosed in U.S. Patent 5,193,136, issued March 9, 1993, and entitled PROCESS FOR MAKING MULTIFUNCTION INTEGRATED OPTICS CHIPS HAVING HIGH ELECTRO-OPTIC COEFFICIENTS. By this reference, the entire disclosure of that patent is incorporated herein by reference.

Alternatively, the waveguides and phase modulators may be made by treating lithium niobate wafers with an aqueous solution of benzoic acid and lithium benzoate, for a period of time in the range of about 0.5 to about 20 hours, at a temperature in the range of about 150 °C to about 300 °C, and for a time sufficient to diffuse the desired quantity of lithium ions into the waveguide or phase modulator.

Another alternative method for making the waveguides and phase modulators is to subject lithium niobate wafers to proton exchange as described in U. S. Patent 5,193,136, ~~and then subject~~ing the proton exchanged~~-wafers to thermal anneal~~ing, as described in that patent, but in the presence of a lithium ion-rich environment, such as an environment comprising lithium niobate powder. The annealing step is carried out for substantially the same time periods and at substantially the same temperatures, in the presence of ~~oxygen,~~ as described in U. S. Patent 5,193,136.

The waveguides and phase modulators of this invention may also contain titanium. To make such waveguides and modulators, titanium in-diffusion into the waveguides or the modulators is carried out in the presence of lithium niobate or another lithium ion source so that the waveguide or wafer is impregnated with titanium and lithium ions seriatim or substantially simultaneously.

The term "titanium in-diffusion" refers to a process of masking a surface on a substrate upon which a waveguide trace is formed. The mask delineates the surface boundaries of the waveguide trace. The masked surface is exposed to a titanium-rich environment. At elevated temperatures the titanium ions invade or diffuse into the waveguide trace area exposed by the mask. Heat is used to increase the rate of diffusion of the

titanium ions. Alternatively, creating a titanium-rich environment to cover or surround the lithium niobate substrate produces a concentration gradient between the environment and the substrate. Ions move and diffuse from the higher concentration regions into the regions of lower concentration.

BRIEF DESCRIPTION OF THE DRAWINGS

This invention can be better understood by reference to the drawings, in which:

FIG. 1 is a schematic representation of a multifunction integrated optics chip (MIOC) based on a lithium niobate substrate and including a channel waveguide electro-optic phase modulator made of lithium niobate and including sufficient lithium ions to minimize phase relaxation;

FIG. 2A is a graph showing a typical electrical step signal for application to a phase modulator of this invention; and

FIG. 2B shows the change in phase of the light waves passing through such a modulator.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows a lithium niobate-based, multifunction integrated optics chip, in which the channel waveguide electro-optic phase modulator includes sufficient lithium ions such that, when an electrical signal as shown in FIG. 2A is applied to the waveguide, the phase modulator output amplitude conforms to the solid line shown in FIG. 2B, rather than the dotted line shown in FIG. 2B. As FIG. 2B shows, the phase of light passing through the waveguide changes substantially instantaneously, and, here, in a time period of less than about one microsecond, upon application of an electrical signal to the waveguide shown in FIG. 1. The waveguide of FIG. 1 finds particular application in a fibre-optic gyro.

The waveguide shown in FIG. 1 was made as follows. First, the lithium niobate wafer from which the waveguide was made was inserted into a closed chamber with lithium niobate powder. Oxygen was delivered to this chamber continuously at the rate of about 250 milliliters per hour. The temperature in the chamber was raised from ambient to about 1,050°C incrementally at the rate of 20° per minute. After the temperature in the chamber rose to 1,050°C, the chamber was held at that temperature for about 7 hours. Thereafter, the chamber was opened, and the temperature was allowed to fall rapidly from 1,050°C to 20°C. The wafer was then subjected to the proton exchange method described in U. S. Patent 5,193,163 and the waveguide was made from the resulting wafer. Application of a step electrical signal to this waveguide showed a substantial reduction in the phase relaxation phenomenon.

In preferred embodiments, the method is as follows. A ceramic plate is cleaned with a solvent such as isopropyl alcohol, then dried with an inert gas such as nitrogen. Small pieces of lithium niobate are then placed on the plate. The lid of the plate is cleaned with a solvent such as isopropyl alcohol, and then dried with an inert gas such as nitrogen. Thereafter, the lid is placed over the plate. The covered plate is placed in a furnace, heated to a temperature of about 1,050°C in 20°C/minute increments, and then maintained at about 1.050°C for about 7 hours. During the heating, oxygen is delivered into the chamber at the rate of about 250 milliliters per hour. Thereafter, the furnace is permitted to cool, the lid is removed, the lithium niobate wafer pieces are removed from the plate, and are then subjected to the proton exchange annealing process as described in U. S. Patent 5,193,136.

Claims

1. A lithium niobate optical waveguide comprising sufficient lithium ions such that the change in the phase of a light signal passing through the waveguide effected by an electrical signal applied to the waveguide is substantially instantaneous.

2. A waveguide according to claim 1 wherein the quantity of lithium ions in the waveguide is sufficient to cause the phase of a light signal passing through the waveguide to change to a steady state value in less than one microsecond.

3. A waveguide according to claim 1 or 2 further comprising titanium ions.

4. A fibre-optic gyro comprising a waveguide according to any preceding claim.

5. A lithium niobate channel waveguide electro-optic phase modulator comprising sufficient lithium ions such that the change in the phase of a light signal passing through the modulator effected by an electrical signal applied to the modulator is substantially instantaneous.

6. A phase modulator according to claim 5 wherein the quantity of lithium ions in the modulator is sufficient to cause the phase of a light signal passing through the modulator to change to a steady state value in less than one microsecond.

7. A phase modulator according to claim 5 or 6 further comprising titanium ions.

8. A fibre-optic gyro comprising a phase modulator according to claim 5, 6 or 7.

9. A method for producing an optical waveguide or a channel waveguide electro-optic phase modulator comprising heating a lithium niobate optical waveguide or channel waveguide electro-optic phase modulator in the presence of oxygen and lithium ions and at a temperature and for a time sufficient to produce a waveguide or modulator comprising sufficient lithium ions such that the change in the phase of a light signal passing through the optical waveguide or the channel waveguide electro-optic phase modulator effected by an electrical signal applied to the waveguide or modulator is substantially instantaneous.

10. A method for producing a waveguide substrate comprising heating a lithium niobate wafer in the presence of oxygen and lithium ions at a temperature and for a time sufficient to produce a substrate comprising sufficient lithium ions that the change in the phase of a light signal passing through an optical waveguide or channel waveguide electro-optic phase modulator traced on the substrate is substantially instantaneous.

11. The method of claim 9 or 10 wherein the heat treatment takes place at a temperature of approximately 1000 • C.

12. The method of any of claims 9 to 11 further comprising titanium in-diffusion into the waveguide or modulator.

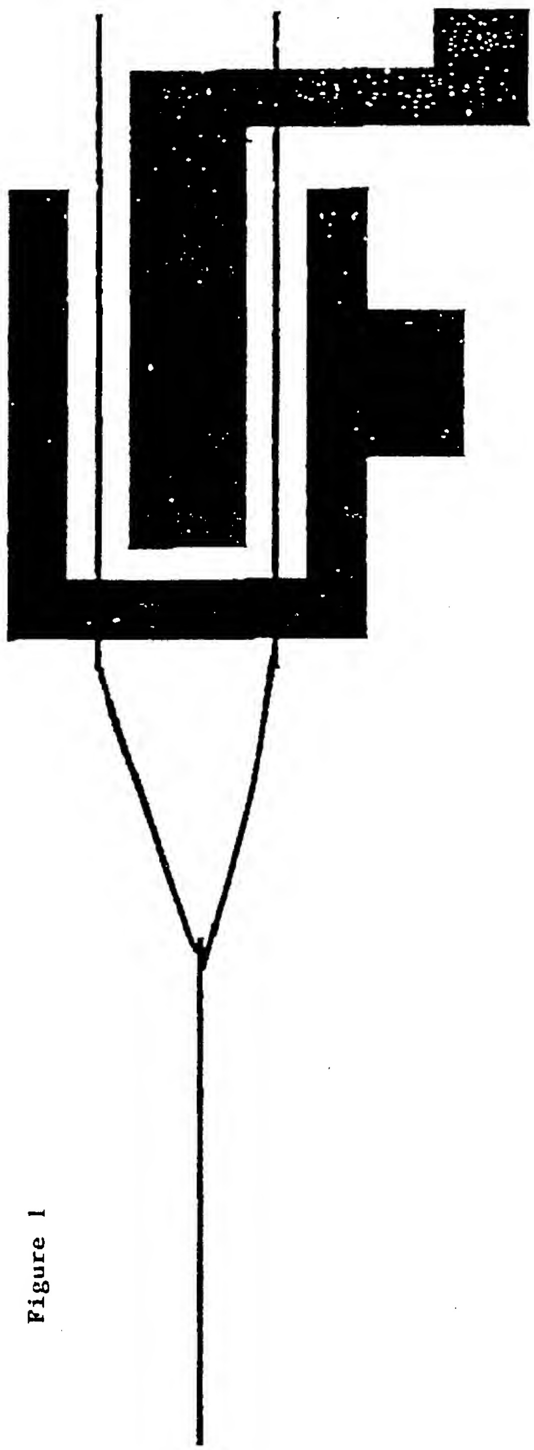

Figure 1

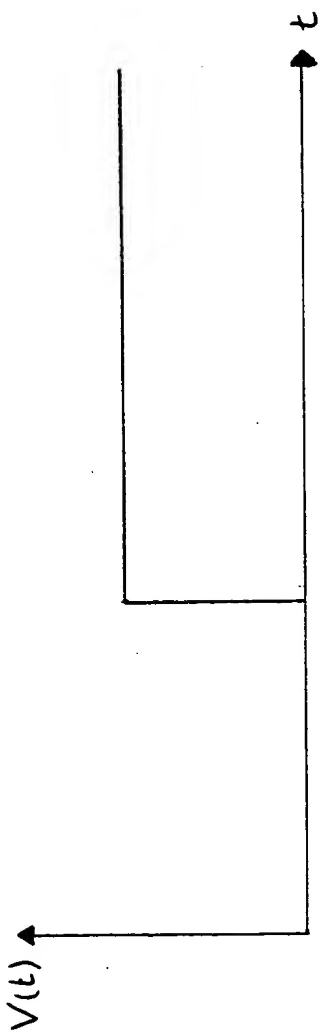

Figure 2a

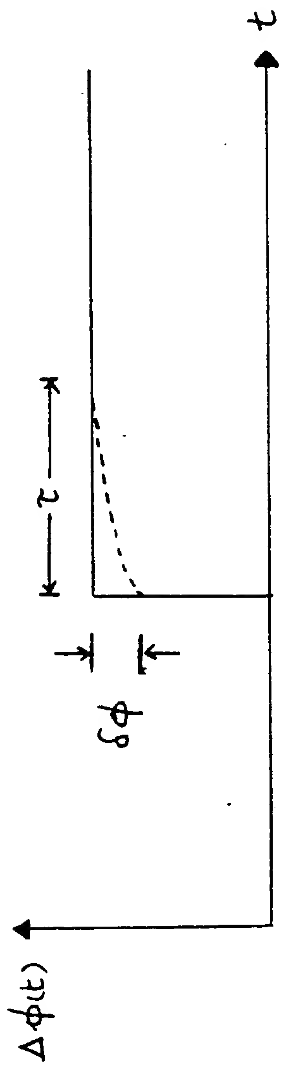

Figure 2b

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 30 4213

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
D,A	US-A-5 193 136 (C. L. CHANG ET AL.) 9 March 1993 * claim 1 * ---	1-12	G02B6/12
A	IEEE PHOTONICS TECHNOLOGY LETTERS, vol.4, no.8, August 1992, NEW YORK US pages 881 - 883 P. JIANG 'Buried optical waveguide polarizer by titanium indiffusion and proton-exchange in LiNbO3' see section "Experiment", first paragraph ---	1-12	
A	EP-A-0 397 895 (SELENIA INDUSTRIE ELETTRONICHE ASSOCIATE SPA) 22 November 1990 * column 1, line 28 - column 2, line 23 * ---	1-12	
A	PATENT ABSTRACTS OF JAPAN vol. 12, no. 185 (P-710) (3032) 31 May 1988 & JP-A-62 293 206 (MATSUSHITA ELECTRIC IND CO LTD) 19 December 1987 * abstract * -----	1-12	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G02B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	11 November 1994	Sarneel, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

THIS PAGE BLANK (USPTO)